INFORMATION ABOUT THE NEUTRINO MASS MATRIX FROM DOUBLE BETA DECAY

H.V. KLAPDOR-KLEINGROTHAUS
Max-Planck-Institut für Kernphysik,
P.O. Box 10 39 80, D-69029 Heidelberg, Germany
Spokesman of HEIDELBERG-MOSCOW and GENIUS Collaborations
E-mail: klapdor@gustav.mpi-hd.mpg,
Home-page: http://mpi-hd.mpg.de.non_acc/

Double beta decay is indispensable to solve the question of the neutrino mass matrix *together* with ν oscillation experiments. The most sensitive experiment since eight years — the HEIDELBERG-MOSCOW experiment in Gran-Sasso — already now, with the experimental limit of $\langle m_\nu \rangle < 0.26$ eV excludes degenerate ν mass scenarios allowing neutrinos as hot dark matter in the universe for the small angle MSW solution of the solar neutrino problem. It probes cosmological models including hot dark matter already now on the level of future satellite experiments MAP and PLANCK. It further probes many topics of beyond Standard Model physics at the TeV scale. Future experiments should give access to the multi-TeV range and complement on many ways the search for new physics at future colliders like LHC and NLC. For neutrino physics some of them (GENIUS) will allow to test almost *all* neutrino mass scenarios allowed by the present neutrino oscillation experiments. A GENIUS Test Facility has just been funded and will come into operation by end of 2001.

1 Introduction

Recently atmospheric and solar neutrino oscillation experiments have shown that neutrinos are massive. This is the first indication of beyond standard model physics. The absolute neutrino mass scale is, however, still unknown, and only neutrino oscillations and neutrinoless double beta decay *together* can solve this problem (see, e.g. [1,2,3]).

In this paper we will discuss the contribution, that can be given by present and future $0\nu\beta\beta$ experiments to this important question of particle physics. We shall, in section 2, discuss the expectations for the observable of neutrinoless double beta decay, the effective neutrino mass $\langle m_\nu \rangle$, from the most recent ν oscillation experiments, which tells us the required sensitivity for future $0\nu\beta\beta$ experiments. In section 3 we shall discuss the present status and future potential of $0\nu\beta\beta$ experiments. It will be shown, that if by exploiting the potential of $0\nu\beta\beta$ decay to its ultimate experimental limit, it will be possible to test practically *all* neutrino mass scenarios allowed by the present neutrino oscillation experiments (except for one, the hierarchical LOW solution).

2 Allowed ranges of $\langle m \rangle$ by ν oscillation experiments

After the recent results from Superkamiokande (e.g. see [21,22]), the prospects for a positive signal in $0\nu\beta\beta$ decay have become more promising. The observable of double beta decay $\langle m \rangle = |\sum U_{ei}^2 m_i| = |m_{ee}^{(1)}| + e^{i\phi_2}|m_{ee}^{(2)}| + e^{i\phi_3}|m_{ee}^{(3)}|$ with U_{ei} denoting elements of the neutrino mixing matrix, m_i neutrino mass eigenstates, and ϕ_i relative Majorana CP phases, can be written in terms of oscillation parameters [1,2]

$$|m_{ee}^{(1)}| = |U_{e1}|^2 m_1, \tag{1}$$

$$|m_{ee}^{(2)}| = |U_{e2}|^2 \sqrt{\Delta m_{21}^2 + m_1^2}, \tag{2}$$

$$|m_{ee}^{(3)}| = |U_{e3}|^2 \sqrt{\Delta m_{32}^2 + \Delta m_{21}^2 + m_1^2}. \tag{3}$$

The effective mass $\langle m \rangle$ is related with the half-life for $0\nu\beta\beta$ decay via $\left(T_{1/2}^{0\nu}\right)^{-1} \sim \langle m_\nu \rangle^2$, and for the limit on $T_{1/2}^{0\nu}$ deducible in an experiment we have $T_{1/2}^{0\nu} \sim a\sqrt{\frac{Mt}{\Delta E B}}$. Here a is the isotopical abundance of the $\beta\beta$ emitter; M is the active detector mass; t is the measuring time; ΔE is the energy resolution; B is the background count rate.

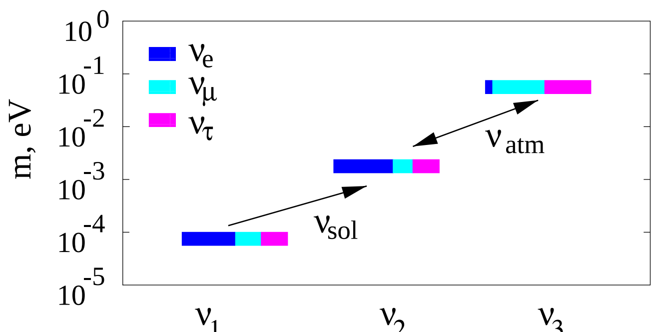

Figure 1. Neutrino masses and mixings in the scheme with mass hierarchy. Coloured bars correspond to flavor admixtures in the mass eigenstates ν_1, ν_2, ν_3. The quantity $\langle m \rangle$ is determined by the dark blue bars denoting the admixture of the electron neutrino U_{ei}.

Neutrino oscillation experiments fix or restrict some of the parameters in (1)–(3), e.g. in the case of normal hierarchy solar neutrino experiments yield Δm_{21}^2, $|U_{e1}|^2 = \cos^2\theta_\odot$ and $|U_{e2}|^2 = \sin^2\theta_\odot$. Atmospheric neutrinos fix Δm_{32}^2, and experiments like CHOOZ, looking for ν_e disappearance restrict $|U_{e3}|^2$. The phases ϕ_i and the mass of the lightest neutrino, m_1 are free parameters. The expectations for $\langle m \rangle$ from oscillation experiments in different

neutrino mass scenarios have been carefully analyzed in[1,2]. In sections 2.1 to 2.3 we give some examples.

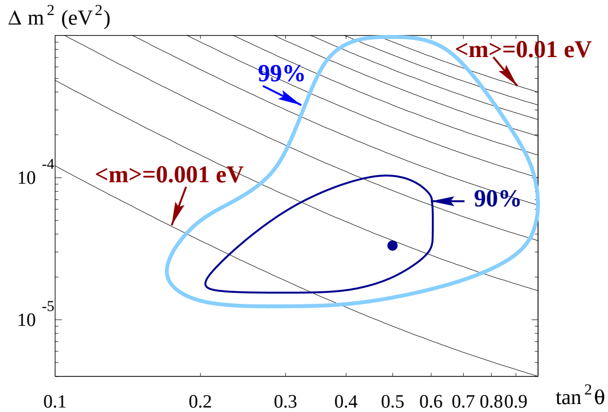

Figure 2. Double beta decay observable $\langle m \rangle$ and oscillation parameters in the case of the MSW large mixing angle solution of the solar neutrino deficit, where the dominant contribution to $\langle m \rangle$ comes from the second state. Shown are lines of constant $\langle m \rangle$, the lowest line corresponding to $\langle m_\nu \rangle = 0.001$ eV, the upper line to 0.01 eV. The inner and outer closed line show the regions allowed by present solar neutrino experiments with 90% C.L. and 99% C.L., respectively. Double beta decay with sufficient sensitivity could check the LMA MSW solution. Complementary information could be obtained from the search for a day-night effect and spectral distortions in future solar neutrino experiments as well as a disappearance signal in KAMLAND.

2.1 Hierarchical spectrum $(m_1 \ll m_2 \ll m_3)$

In hierarchical spectra (Fig. 1), motivated by analogies with the quark sector and the simplest see-saw models, the main contribution comes from m_2 or m_3. For the large mixing angle (LMA) MSW solution which is favored at present for the solar neutrino problem (see [21]), the contribution of m_2 becomes dominant in the expression for $\langle m \rangle$, and

$$\langle m \rangle \simeq m_{ee}^{(2)} = \frac{\tan^2\theta}{1+\tan^2\theta}\sqrt{\Delta m^2_\odot}. \qquad (4)$$

In the region allowed at 90% C.L. by Superkamiokande according to [22], the prediction for $\langle m \rangle$, becomes

$$\langle m \rangle = (1 \div 3) \cdot 10^{-3} \mathrm{eV}. \qquad (5)$$

The prediction extends to $\langle m \rangle = 10^{-2}$ eV in the 99% C.L. range (Fig. 2).

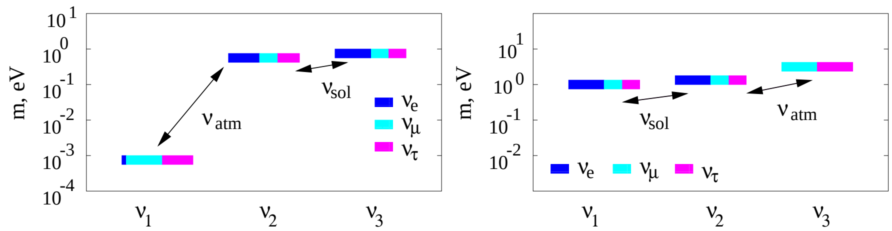

Figure 3. Left: Neutrino masses and mixing in the inverse hierarchy scenario. Right: Neutrino masses and mixings in the degenerate scheme.

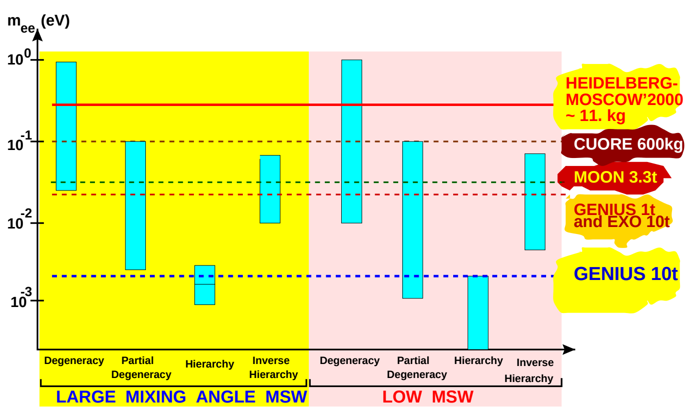

Figure 4. Summary of values for $m_{ee} = \langle m \rangle$ expected from neutrino oscillation experiments (status NEUTRINO2000), in the different schemes discussed in this paper. For a more general analysis see [1]. The expectations are compared with the recent neutrino mass limits obtained from the HEIDELBERG-MOSCOW [7,23], experiment as well as the expected sensitivities for the CUORE [53], MOON [50], EXO [51] proposals and the 1 ton and 10 ton proposal of GENIUS [12,13].

2.2 *Inverse Hierarchy* ($m_3 \approx m_2 \gg m_1$)

In inverse hierarchy scenarios (Fig. 3) the heaviest state with mass m_3 is mainly the electron neutrino, its mass being determined by atmospheric neutrinos, $m_3 \simeq \sqrt{\Delta m^2_{\rm atm}}$. For the LMA MSW solution one finds [2]

$$\langle m \rangle = (1 \div 7) \cdot 10^{-2} \mathrm{eV}. \tag{6}$$

2.3 Degenerate spectrum ($\boldsymbol{m_1 \simeq m_2 \simeq m_3 \gtrsim 0.1}$ *eV*)

In degenerate scenarios (fig. 3) the contribution of m_3 is strongly restricted by CHOOZ. The main contributions come from m_1 and m_2, depending on their admixture to the electron flavors, which is determined by the solar neutrino solution. We find [2]

$$m_{\rm min} < \langle m \rangle < m_1 \qquad \text{with} \qquad \langle m_{\rm min} \rangle = (\cos^2\theta_\odot - \sin^2\theta_\odot)\, m_1. \qquad (7)$$

This leads for the LMA solution to $\langle m \rangle = (0.25 \div 1) \cdot m_1$, the allowed range corresponding to possible values of the unknown Majorana CP-phases.

After these examples we give a summary of our analysis [1,2] of the $\langle m \rangle$ allowed by ν oscillation experiments for neutrino mass models in the presently favored scenarios, in Fig. 4. The size of the bars corresponds to the uncertainty in mixing angles and the unknown Majorana CP-phases.

3 Status of $\beta\beta$ Experiments

The status of present double beta experiments is shown in Fig. 5 and is extensively discussed in [3]. The HEIDELBERG-MOSCOW experiment using the largest source strength of 11 kg of enriched ^{76}Ge in form of five HP Ge-detectors in the Gran-Sasso underground laboratory [3,38], yields after a time of 37.2 kg·y of measurement (Fig. 6) a half-life limit of [23,24]

$$T^{0\nu}_{1/2} > 2.1(3.5) \cdot 10^{25} \text{ y}, \quad 90\% \ (68\%) \text{ C.L.}$$

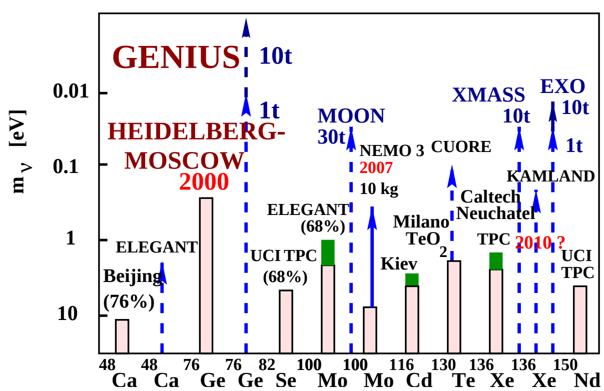

Figure 5. Present situation, 2000, and expectation for the future, of the most promising $\beta\beta$ experiments. Light parts of the bars: present status; dark parts: expectation for running experiments; solid and dashed lines: experiments under construction or proposed experiments, respectively. For references see [3,42,68].

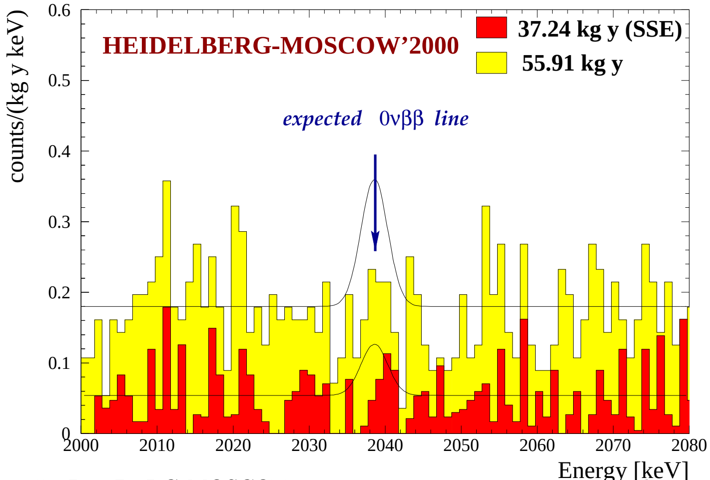

Figure 6. HEIDELBERG-MOSCOW experiment: energy spectrum in the range between 2000 keV and 2080 keV, where the peak from neutrinoless double beta decay is expected. The open histogram denotes the overall sum spectrum without PSA after 55.9 kg y of measurement (since 1992). The filled histogram corresponds to the SSE data after 37.2 kg y. Shown are also the excluded (90% C.L.) peak areas from the two spectra.

and a limit for the effective neutrino mass of

$$\langle m \rangle < 0.34(0.26)\ \mathrm{eV}, \quad 90\%\ (68\%)\ \mathrm{C.L.}$$

This sensitivity just starts to probe some (degenerate) neutrino mass models (see Fig. 4). In degenerate models from the experimental limit on $\langle m \rangle$ we can conclude an upper bound on the mass scale of the heaviest neutrino. For the LMA solar solution we obtain from (7) $m_{1,2,3} < 1.1\,\mathrm{eV}$ implying $\sum m_i < 3.2\,\mathrm{eV}$. This first number is sharper than what has recently been deduced from single beta decay of tritium ($m < 2.2$ eV [31]), and the second is sharper than the limit of $\sum m_i < 5.5\,\mathrm{eV}$ still compatible with most recent fits of Cosmic Microwave Background Radiation and Large Scale Structure data (see, e.g. [32]).

The result has found a large resonance, and it has been shown that it excludes for example the small angle MSW solution of the solar neutrino problem in degenerate scenarios, if neutrinos are considered as hot dark matter in the universe[27,28,29,30]. This conclusion has been made, *before* the SMA MSW solution has been disfavored by the SUPERKAMIOKANDE collaboration in June 2000. Figure 7 shows that the present sensitivity probes cosmological

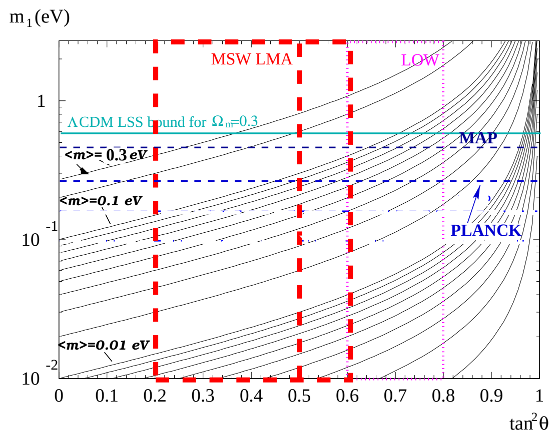

Figure 7. Double beta decay observable $\langle m \rangle$ and oscillation parameters: The case for degenerate neutrinos. Plotted on the axes are the overall scale of neutrino masses m_0 and mixing $\tan^2 2\theta_{12}$. Also shown is a cosmological bound deduced from a fit of CMB and large scale structure [20] and the expected sensitivity of the satellite experiments MAP and PLANCK. The present limit from tritium β decay of 2.2 eV [31] would lie near the top of the figure. The range of $\langle m \rangle$ investigated at present by the HEIDELBERG-MOSCOW experiment is, in the case of small solar neutrino mixing already in the range to be explored by MAP and PLANCK [20].

models including hot dark matter already now on a level of future satellite experiments MAP and PLANCK. It starts to become interesting also in connection with 'Z-burst' models recently discussed as explanation for super-high energy cosmic ray events beyond the GZK cutoff energy[14,15,17,16].

The HEIDELBERG-MOSCOW experiment, yields now since eight years already the by far sharpest limits worldwide. If future searches will show that $\langle m \rangle > 0.1$ eV, then the three-ν mass schemes, which will survive, are those with ν mass degeneracy, and in 4-neutrino schemes, those with inverse mass hierarchy (Fig. 4 and see also ref.[1]).

It has been discussed in detail earlier (see e.g.[3,12,18,26]), that of present generation experiments no one has a potential to probe $\langle m \rangle$ below the present HEIDELBERG-MOSCOW level (see Fig. 5).

A second experiment using enriched ^{76}Ge, IGEX, has stopped operation by end of 1999 [62]. This experiment already started in 1992 with 2.1 kg of ^{76}Ge [66] and operated in 1995 already 8 kg of ^{76}Ge [65]. In 1999 they published a measuring time of 5.7 kg y (less than one year of full operation) [63,64], and

in autumn 99 of about 9 kg y [61] (less than one quarter of the HEIDELBERG-MOSCOW significance) and an optimistic value for $\langle m \rangle$, using a method criticized. The Milano cryogenic experiment using TeO_2 bolometers improved their values for the $\langle m_\nu \rangle$ from $\beta\beta$ decay of ^{130}Te, from 5.3 eV in 1994[55] to 1.8 eV in 2000[56], and according to[54] to 0.9 eV in early 2001. Also CUORICINO (with 45 kg of detectors) scheduled for starting in autumn 2001[54] will hardly reach the HEIDELBERG-MOSCOW limit (see also discussion in [76]). NEMO-III, originally aiming at a sensitivity of 0.1 eV, reduced their goals recently to $0.3 \div 0.7$ eV (see[59]), (which is more consistent with estimates given by[58]), to be reached in 6 years from starting of running, foreseen for the year 2002.

A possibility to probe $\langle m \rangle$ down to ~ 0.1 eV (90% c.l.) exists with the GENIUS Test Facility[24] (see below), which should reduce the background by a factor of 30 compared to the HEIDELBERG-MOSCOW experiment, and thus could reach a half-life limit of $1.5 \cdot 10^{26}$ y.

4 Future of $\beta\beta$ Experiments

To extend the present sensitivity of $\beta\beta$ experiments below a limit of 0.1 eV, requires completely new experimental approaches, as discussed extensively in[3,12,13,18].

Figure 4 shows that an improvement of the sensitivity down to $\langle m \rangle \sim 10^{-3}$ eV is required to probe all neutrino mass scenarios allowed by present neutrino oscillation experiments[12,1]. With this result of ν oscillation experiments nature seems to be generous to us since such a sensitivity seems to be achievable in future $\beta\beta$ experiments, if this method is exploited to its ultimate limit, as by the GENIUS project[3,12,13,18,19,33,37,39,40,42].

4.1 GENIUS, Double Beta Decay and the Light Majorana Neutrino Mass

With the era of the HEIDELBERG-MOSCOW experiment which will remain the most sensitive experiment for the next years, the time of the small smart experiments is over.

The requirements in sensitivity for future experiments to play a decisive role in the solution of the structure of the neutrino mass matrix can be read from Fig. 4.

To reach the required level of sensitivity $\beta\beta$ experiments have to become large. On the other hand source strengths of up to 10 tons of enriched material touch the world production limits. At the same time the background has to be reduced by a factor of 1000 and more compared to that of the HEIDELBERG-MOSCOW experiment.

Table 1 lists some key numbers for GENIUS,[12,13,37] which was the first proposal for a third generation double beta experiment, and which may be *the only* project, which will be able to test *all* neutrino mass scenarios, and of some other proposals made *after* the GENIUS proposal. The potential of some of them is shown also in Fig. 4 and Fig. 5. It is seen that not all of these proposals fully cover the region to be probed. Among them is also the recently presented MAJORANA project [67], which does not really apply any new strategy for background reduction. For more recent information on XMASS, EXO, MOON experiments see the contributions of Y. Suzuki, G. Gratta and H. Ejiri in these Proceedings[68]. The CAMEO project[76] will have to work on *very* long time scales, also since it has to wait the end of the BOREXINO solar neutrino experiment. CUORE[57] has, with the complexity of cryogenic techniques, still to overcome serious problems of background to enter into interesting regions of $\langle m_\nu \rangle$. EXO[51] needs still very extensive research and development to probe the applicability of the proposed detection method.

In the GENIUS project a reduction by a factor of more than 1000 down to a background level of 0.1 events/tonne y keV in the range of $0\nu\beta\beta$ decay is reached by removing all material close to the detectors, and by using naked Germanium detectors in a large tank of liquid nitrogen. It has been shown that the detectors show excellent performance under such conditions[13,12].

For technical questions and extensive Monte Carlo simulations of the GENIUS project for its application in double beta decay we refer to[13,37].

4.2 GENIUS and Other Beyond Standard Model Physics

GENIUS will allow besides the major step in neutrino physics described above the access to a broad range of other beyond SM physics topics in the multi-TeV range. Already now $\beta\beta$ decay probes the TeV scale on which new physics should manifest itself (see, e.g.[12,39,40]). Basing to a large extent on the theoretical work of the Heidelberg group in the last five years, the HEIDELBERG-MOSCOW experiment yields results for SUSY models (R-parity breaking, neutrino mass), leptoquarks (leptoquarks-Higgs coupling), compositeness, right-handed W mass, nonconservation of Lorentz invariance and equivalence principle, mass of a heavy left or righthanded neutrino, competitive to corresponding results from high-energy accelerators like TEVATRON and HERA. The potential of GENIUS extends into the multi-TeV region for these fields and its sensitivity would correspond to that of LHC or NLC and beyond (for details see[3,39,40]).

5 GENIUS-Test Facility

Construction of a test facility for GENIUS — GENIUS-TF — consisting of $\sim$ 40 kg of HP Ge detectors suspended in a liquid nitrogen box has been started. Up to end of January 2001, four detectors each of $\sim$ 2.5 kg and with a threshold of as low as $\sim$ 500 eV have been produced.

Besides test of various parameters of the GENIUS project, the test facility would allow, with the projected background of 2–4 events/(kg y keV) in the low-energy range, to probe the DAMA evidence for dark matter by the seasonal modulation signature within about one year of measurement with 95% C.L. Even for an initial lower mass of 20 kg the time scale would be not larger than three years, see (for details see[43,44]). If using the enriched ^{76}Ge detectors of the HEIDELBERG-MOSCOW experiment in the GENIUS-TF setup, a background in the $0\nu\beta\beta$ region a factor 30 smaller than in the HEIDELBERG-MOSCOW experiment could be obtained, which would allow to test the effective Majorana neutrino mass down to 0.15 eV (90% C.L.)[43,44].

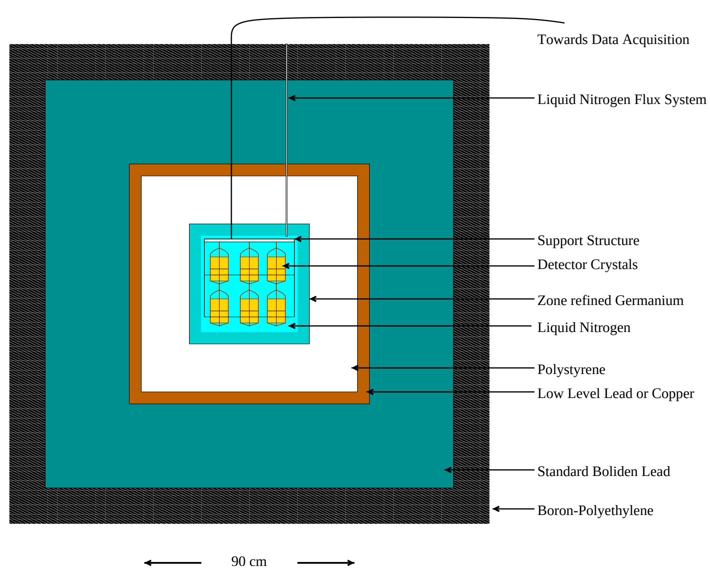

Figure 8. Conceptual design of the Genius TF. Up to 14 detectors will be housed in the inner detector chamber, filled with liquid nitrogen. As a first shield 5 cm of zone refined Germanium will be used. Behind the 20 cm of polystyrene isolation another 35 cm of low level lead and a 15 cm borated polyethylene shield will complete the setup.

Table 1. Some key numbers of future double beta decay experiments (and of the HEIDELBERG-MOSCOW experiment). Explanations: ∇ - assuming the background of the present pilot project. $**$ - with matrix element from [45], [46], [47], [48], [49] (see Table II in [25]). $\triangle$ - this case shown to demonstrate **the ultimate limit** of such experiments. For details see [3].

$\beta\beta-$ *Isoto−* pe	*Name*	*Status*	Mass (*ton− nes*)	Assumed backgr. † events/ kg y keV, ‡ events/kg y FWHM, $*$ events /yFWHM	*Run− ning* Time (tonn. years)	Results limit for $0\nu\beta\beta$ half-life (years)	$<m_\nu>$ (eV)
^{76}**Ge**	**HEIDEL- BERG MOSCOW** [40] [23,7]	**run- ning since 1990**	0.011 (enri- ched)	† 0.06 ‡ 0.24 $*$ 2	**37.24 kg y**	$\mathbf{2.1 \cdot 10^{25}}$ **90% c.l.** $\mathbf{3.5 \cdot 10^{25}}$ **68% c.l.** **NOW !!**	$<$ **0.34** $**$ **90% c.l.** $<$ **0.26** $**$ **68% c.l.** **NOW !!**
^{100}**Mo**	NEMO III [59]	*under constr. end 2001?*	~0.01 (enri- -ched)	† **0.0005** ‡ 0.2 $*$ 2	50 kg y	10^{24}	0.3-0.7
^{130}**Te**	CUORE$^{\nabla}$ [57]	*idea since 1998*	0.75 (natural)	† 0.5 ‡ 4.5/$*$ 1000	5	$9 \cdot 10^{24}$	0.2-0.5
^{130}**Te**	CUORE [57,60]	*idea since 1998*	0.75 (natural)	† 0.005 ‡ 0.045/ $*$ 45	5	$9 \cdot 10^{25}$	0.07-0.2
^{100}**Mo**	MOON [50,68]	*idea since 1999*	10 (enrich.) 100(nat.)	?	30 300	?	 0.03
^{116}**Cd**	CAMEOII CAMEOIII[76]	*idea since 2000*	0.65 1(enr.)	$*$ 3. ?	5-8 5-8	10^{26} 10^{27}	0.06 0.02
^{136}**Xe**	EXO [51,52]	Proposal since 1999	1 10	$*$ 0.4 $*$ 0.6	5 10	$8.3 \cdot 10^{26}$ $1.3 \cdot 10^{28}$	0.05-0.14 0.01-0.04
^{76}**Ge**	**GENIUS - TF** [43,44]	*under constr. end 2001?*	11 kg (enr.)	† $\mathbf{6 \cdot 10^{-3}}$	3	$\mathbf{1.6 \cdot 10^{26}}$	**0.15**
^{76}**Ge**	**GENIUS** [12,13]	Pro- posal since 1997	1 (enrich.) 1	† $\mathbf{0.04 \cdot 10^{-3}}$ ‡ $\mathbf{0.15 \cdot 10^{-3}}$ $*$ **0.15** $*$ **1.5**	1 10	$\mathbf{5.8 \cdot 10^{27}}$ $\mathbf{2 \cdot 10^{28}}$	**0.02-0.05** **0.01-0.028**
^{76}**Ge**	**GENIUS** [12,13]	Pro- posal since 1997	10 (enrich.)	‡ $\mathbf{0.15 \cdot 10^{-3}}$ $\mathbf{0^{\triangle}}$	10 10	$\mathbf{6 \cdot 10^{28}}$ $\mathbf{5.7 \cdot 10^{29}}$	**0.006 - 0.016** **0.002 - 0.0056**

This limit is similar to what some much larger experiments aim at (Table 1).

Table 2. Some of the new projects under discussion for future double beta decay experiments (see ref.[3]).

NEW PROJECTS				
	BACKGROUND REDUCTION	MASS INCREASE	POTENTIAL FOR DARK MATTER	POTENTIAL FOR SOLAR ν's
GENIUS	+	+	+	+ *)
CUORE	(+)	+	−	−
MOON	(+)	+	−	+
EXO	+	+	−	−
MAJORANA	−	+	−	−
*) real time measurement of pp neutrinos with threshold of 10 keV (!!)				

6 Conclusion

Nature is extremely generous to us, that with an increase of the sensitivity by two orders of magnitude compared to the present limit, down to $\langle m_\nu \rangle < 10^{-3}$ eV, indeed essentially all neutrino scenarios allowed by present neutrino oscillation experiments can be probed by double beta decay experiments.

GENIUS is the only of the new projects (see also Table 2) which exploits double beta decay to this ultimate limit. It is also the only one which simultaneously has a huge potential for cold dark matter search, and for real-time detection of low-energy neutrinos (see[12,22,23,36,37,78,42]).

References

1. H.V. Klapdor-Kleingrothaus, H. Päs and A.Yu. Smirnov, *Preprint: hep-ph/***0003219**, (2000) and in *Phys. Rev.* **D** (2001).
2. H.V. Klapdor-Kleingrothaus, H. Päs and A.Yu. Smirnov, in Proc. of DARK2000, Heidelberg, 10-15 July, 2000, Germany, ed. H.V. Klapdor-Kleingrothaus, *Springer, Heidelberg* (2001).
3. H.V. Klapdor-Kleingrothaus, "60 Years of Double Beta Decay", *World Scientific, Singapore* (2001) 1253 p.
4. H.V. Klapdor-Kleingrothaus, H. Päs, *Preprint: physics/***0006024** and *Comm. in Nucl. and Part. Phys.* (2000).

5. H.V. Klapdor-Kleingrothaus, in Proc. Int. Workshop on Low Energy Solar Neutrinos, LowNu2, December 4 and 5 (2000) Tokyo, Japan, ed: Y. Suzuki, *World Scientific, Singapore* (2001).
6. L. Baudis and H.V. Klapdor-Kleingrothaus, *Eur. Phys. J.* **A 5**, 441-443 (1999) and in Proceedings of the 2nd Int. Conf. on Particle Physics Beyond the Standard Model BEYOND'99, Castle Ringberg, Germany, 6-12 June 1999, edited by H.V. Klapdor-Kleingrothaus and I.V. Krivosheina, *IOP Bristol*, 1023 - 1036 (2000).
7. H.V. Klapdor-Kleingrothaus et al., to be publ. 2001 and $http://www.mpi-hd.mpg.de/non\_acc/$
8. HEIDELBERG-MOSCOW Collaboration, *Phys. Rev.* **D 59**, 022001 (1998).
9. L. Baudis, A. Dietz, B. Majorovits, F. Schwamm, H. Strecker and H.V. Klapdor-Kleingrothaus, *Phys. Rev.* **D 63** , 022001 (2000) and *astro-ph/***0008339**
10. Y. Ramachers for the CRESST Collaboration in Proc. of XIth Rencontres de Blois, Frontiers of Matter, France, June 27-July 3, 1999.
11. H.V. Klapdor-Kleingrothaus et al. in Proc. of Third International Conference on Dark Matter in Astro and Particle Physics, DARK2000, Heidelberg, Germany, July 10-15, 2000, *Springer, Heidelberg* (2001), ed. H.V. Klapdor-Kleingrothaus.
12. H.V. Klapdor-Kleingrothaus in Proceedings of BEYOND'97, First International Conference on Particle Physics Beyond the Standard Model, Castle Ringberg, Germany, 8-14 June 1997, edited by H.V. Klapdor-Kleingrothaus and H. Päs, *IOP Bristol* 485-531 (1998)
13. H.V. Klapdor-Kleingrothaus et al. **MPI-Report MPI-H-V26-1999** and *Preprint: hep-ph/***9910205** and in Proceedings of the 2nd Int. Conf. on Particle Physics Beyond the Standard Model BEYOND'99, Castle Ringberg, Germany, 6-12 June 1999, edited by H.V. Klapdor-Kleingrothaus and I.V. Krivosheina, *IOP Bristol*, 915 - 1014 (2000).
14. T.J. Weiler *Phys. Rev. Lett.* **49**, 234 (1982); ibid., *Astrophys. J.* **285**, 495 (1984); E. Roulet *Phys. Rev.* **D 47**, 5247 (1993).
15. T.J. Weiler *Astropart. Phys.* **11** 303 (1999) and in Proceedings of the 2nd Int. Conf. on Particle Physics Beyond the Standard Model BEYOND'99, Castle Ringberg, Germany, 6-12 June 1999, edited by H.V. Klapdor-Kleingrothaus and I.V. Krivosheina, *IOP Bristol*, 1085 (2000), and *hep-ph/* **9710431**.
16. H. Päs and T.J. Weiler, *hep-ph/* **0101091**.
17. D. Fargion et al., *astro-ph/* **9710029** *Astrophys.J.* **517** 725 (1999) Fargion:
18. H.V. Klapdor-Kleingrothaus, in Proc. of 18th Int. Conf. on Neutrino Physics and Astrophysics (NEUTRINO 98), Takayama, Japan, 4-9 Jun 1998, (eds) Y. Suzuki et al. *Nucl. Phys. Proc. Suppl.* **77**, 357 - 368 (1999).
19. H.V. Klapdor-Kleingrothaus, in Proc. of WEIN'98, "Physics Beyond the Standard Model", Proceedings of the Fifth Intern. WEIN Conference, P. Herczeg, C.M. Hoffman and H.V. Klapdor-Kleingrothaus (Editors), *World Scientific,*

Singapore, 275-311 (1999).

20. R.E. Lopez, *astro-ph/***9909414**; J.R. Primack and M.A.K. Gross, *astro-ph/***0007165**; J.R. Primack, *astro-ph/***0007187**; J. Einasto, in Proc. of DARK2000, Heidelberg, Germany, July 10-15, 2000, Ed. H.V. Klapdor-Kleingrothaus, *Springer, Heidelberg*, (2001).
21. Y. Suzuki in Proc. of NEUTRINO2000, *Sudbury, Canada*, June 2000, ed. A.B. McDonald et al. (2001).
22. M.C. Gonzalez-Garcia, M. Maltoni, C. Pena-Garay and J.W.F. Valle, *hep-ph/***0009350**, *Phys. Rev.* **D 63**, 033005 (2001).
23. H.V. Klapdor-Kleingrothaus et al., *Annual Report Gran Sasso 2000* (2001).
24. H.V. Klapdor-Kleingrothaus et al., MPI Heidelberg, *Annual Report 1999-2000* (2001).
25. HEIDELBERG-MOSCOW Coll., *Phys. Rev. Lett.* **83**, 41-44 (1999).
26. H.V. Klapdor-Kleingrothaus, in Proc. of Int. Conference NOW2000 - "Origins of Neutrino Oscillations", *Nucl. Phys.* **B** (2001) ed. G. Fogli.
27. H. Georgi and S.L. Glashow, *Phys. Rev.* **D 61**, 097301 (2000).
28. H. Minakata and O. Yasuda, *Phys. Rev.* **D 56**, 1692 (1997) and H. Minakata, *hep-ph/***0004249**.
29. O. Yasuda in Proc. of Beyond the Desert'99, ed. by H.V. Klapdor-Kleingrothaus and I.V. Krivosheina, *IOP Bristol*, 223 (2000).
30. J. Ellis and S. Lola, *Phys. Lett.* **B 458**, 310 (1999) and *Preprint: hep-ph/***9904279**.
31. C. Weinheimer in Proc. of NEUTRINO2000, Sudbury, Canada, June 16 - June 21 (2000), ed. A.B. McDonald et al. *Nucl. Phys.* **B** (2001).
32. M. Tegmark, M. Zaldarriaga and A.J.S. Hamilton, *Preprint: hep-ph/*0008145.
33. H.V. Klapdor-Kleingrothaus, *Int. J. Mod. Phys.* **A 13**, 3953 (1998).
34. H.V. Klapdor-Kleingrothaus and Y. Ramachers, *Eur. Phys. J.* **A 3**, 85-92 (1998).
35. V.A. Bednyakov and H.V. Klapdor-Kleingrothaus, *Phys. Rev.* **D 62** (2000) 043524/1-9 and *hep-ph/* **9908427**.
36. V.A. Bednyakov and H.V. Klapdor-Kleingrothaus, *Preprint: hep-ph/***0011233** (2000) in press in *Phys. Rev.* **D** (2001).
37. H.V. Klapdor-Kleingrothaus, J. Hellmig and M. Hirsch, *J. Phys.* **G 24**, 483 (1998).
38. H.V. Klapdor-Kleingrothaus, in Proc. of the Int. Symposium on Advances in Nuclear Physics, eds.: D. Poenaru and S. Stoica, *World Scientific, Singapore* , 123-129 (2000).
39. H.V. Klapdor-Kleingrothaus, in Proc. of Int. Symposium on Lepton and Baryon Number Violation, Trento, Italy, 20-25 April, 1998, ed. H.V. Klapdor-Kleingrothaus and I.V. Krivosheina, *IOP, Bristol*, (1999) 251-301 and *Preprint: hep-ex/***9901021**
40. H.V. Klapdor-Kleingrothaus, *Springer Tracts in Modern Physics*, **163**, 69-104 (2000), *Springer-Verlag, Heidelberg, Germany* (2000).

41. J. Ellis, A. Ferstl and K.A. Olive, *Phys. Lett.* **B 481**, 304–314 (2000) and *Preprint: hep-ph/***0001005** and *Preprint: hep-ph/***0007113**.
42. H.V. Klapdor-Kleingrothaus, in Proc. Int. Workshop on Low Energy Solar Neutrinos, LowNu2, Dec. 4-5. ed: Y. Suzuki et al. *World Scientific, Singapore* (2001).
43. H.V. Klapdor-Kleingrothaus, L.Baudis, A.Dietz, G.Heusser, I.Krivosheina, B.Majorovits, H. Strecker, S.T. Belyaev, V.I. Lebedev and coworkers, Internal Report **MPI-H-V32-2000**.
44. L. Baudis, A. Dietz, G. Heusser, B. Majorovits, H. Strecker, and H.V. Klapdor-Kleingrothaus, *hep-ex/***0012022**, submitted for publication.
45. A. Staudt, K. Muto and H.V. Klapdor-Kleingrothaus, *Europhys. Lett.* **13** , 31 (1990).
46. T. Tomoda Rept. *Prog. Phys.* **54**, 53 - 126 (1991).
47. W.C. Haxton and G.J. Stephenson, *Prog. Part. Nucl. Phys.* **12**, 409 - 479 (1984).
48. X.R. Wu, A. Staudt, H.V. Klapdor-Kleingrothaus, Cheng-Rui Ching and Tso-Hsiu Ho, *Phys. Lett.* **B 272** , 169 - 172 (1991).
49. X.R. Wu, A. Staudt, T.T.S. Kuo and H.V. Klapdor-Kleingrothaus, *Phys. Lett.* **B 276**, 274 - 278 (1992).
50. H. Ejiri et al., *Phys. Rev. Lett.* **85**, 2917–2920 (2000) and *Preprint: nucl-ex/***9911008**.
51. M. Danilov et al., *Phys. Lett.* **B 480**, 12 - 18 (2000).
52. G. Gratta in Proc. International Workshop on Low Energy Solar Neutrinos, LowNu2, December 4 and 5 (2000) Tokyo, Japan, ed: Y. Suzuki, World Scientific, Singapore (2001), home page: *http://www-sk.icrr.u-tokyo.ac.jp/neutlowe/2/ transparency/index.html*
53. E. Fiorini et al., *Phys. Rep.* **307**, 309 (1998).
54. E. Fiorini, *priv. Communication*, (Jan. 2001).
55. A. Alessandrello et al., *Phys. Lett.* **B 335**, 519-525 (1994).
56. A. Alessandrello et al., *Phys. Lett.* **B 486**, 13-21 (2000) and S. Pirro et al., *Nicl. Instr. Methods* **A 444**, 71-76 (2000).
57. A. Giuliani (CUORE Collaboration), in Proc. 'Lepton and Baryon Number Violation in Particle Physics, Astrophysics and Cosmology', eds. H.V. Klapdor-Kleingrothaus and I.V.Krivosheina, Trento, Italy, April 20 - April 25, 1998, *IOP, Bristol*, 302 - 308 (1999).
58. V.I. Tretyak and Yu.G. Zdesenko, *At. Data Nucl. Data Tables* **61**, 43 - 62 (1995).
59. NEMO Collaboration, Contributed paper for XIX International Conference on Neutrino Physics and Astrophysics, NEUTRINO2000, Sudbury, Canada, June 16 - 21, 2000 LAL 00-31 (2000) 1 - 10 and NEMO-III Collaboration in Proc. Intern. Conf. of NANPino2000, Dubna, Russia, July 2000, ed. V. Bednjakov et al. (2001).
60. E. Fiorini in Proc. of Intern. Conf. NEUTRINO2000, Sudbury, Canada, June

2000, ed. A.B. MacDonald et al. *Nucl. Phys.* **B** (2001).
61. D. Gonzalez et al. (IGEX Collaboration), in Proc. of TAUP99, Paris, France, 1999, *Nucl. Phys. Proc. Suppl.* **87**, 278 - 280 (2000).
62. I.V. Kirpichnikov, *priv. communication*, (June 2000).
63. C.E. Aalseth et al. (IGEX Collaboration), in Proc. of (TAUP 97), Gran Sasso, Italy, 7 - 11 September 1997, *Nucl. Phys. Proc. Suppl.* **70**, 236 - 238 (1999).
64. C.E. Aalseth (IGEX Collaboration), *Phys. Rev.* **C 59** , 2108 - 2113 (1999).
65. C.E. Aalseth et al. (IGEX Collaboration), in Proc. of 5th Int. Workshop on Topics in Astroparticle and Underground Physics (TAUP 95), Toledo, Spain, 17 - 21 September 1995, *Nucl. Phys. Proc. Suppl.* **48**, 223 - 225 (1996).
66. R.L. Brodzinski et al. (IGEX Collaboration), in Proc. of 15th Int. Conference on Neutrino Physics and Astrophysics (NEUTRINO'92), Granada, Spain, 7 - 12 June, 1992, *Nucl. Phys. Proc. Suppl.* **31**, 76 - 79 (1993).
67. L. DeBraekeleer, talk given at Workshop on the Next Generation U.S. Underground Science Facility, WIPP, June 12-14, 2000, Carlsbad, New Mexico, USA, home-page: *http://www.wipp.carlsbad.nm.us/leptontown/workshoptalks/debraekeleer1/index.htm*
68. Proc. Int. Workshop on Low Energy Solar Neutrinos, LowNu2, December 4 and 5 (2000) Tokyo, Japan, ed: Y. Suzuki, World Scientific, Singapore (2001), home page: *http://www-sk.icrr.u-tokyo.ac.jp/neutlowe/2/transparency/index.html*
69. Y. Suzuki for the collaboration, *Preprint: hep-ph/***0008296**.
70. M. Fujiwara et al., *Phys. Rev. Lett.* **85**, 4442-4445 (2000) and *Preprint: nucl-ex/***0006006**: M. Bhattacharya et al. *Phys. Rev. Lett.* **85**, 4446-4449 (2000) and *Preprint: nucl-ex/***0006005**.
71. see: *http://www.sns.ias.edu.jnb/*
72. J. Edsjö, Neutralinos as dark matter - can we see them? Seminar in Department of Physics, Stockholm University, October 12, 1999, home page: *http://www.physto.se/edsjo/*
73. R. Bernabei et al., *Nucl. Phys.* **B 70** (Proc. Suppl), 79 (1998).
74. R. Bernabei et al., *Phys. Lett.* **B 424**, 195 (1998), *Phys. Lett.* **B 450**, 448 (1999), *Phys. Lett.* **B 480**, 23 (2000).
75. R. Abusaidi et al. (CDMS Collaboration), *Nucl. Instrum. Meth.* **A 444**, 345 (2000), Phys. *Rev. Lett.* **84**, 5699 - 5703 (2000).
76. G. Bellini et al. *Phys. Lett.* **B 493**, 216 - 228 (2000).
77. H.V. Klapdor-Kleingrothaus et al. Proc. DARK2000, Heidelberg, Germany, July 10-15, 2000, Ed. H.V. Klapdor-Kleingrothaus, *Springer, Heidelberg* (2001).
78. H.V. Klapdor-Kleingrothaus, in Proc. of Intern. Workshop Non-Accelerator New Physics in neutrino observations, NANPino-2000, Dubna, July 19-22, 2000, to be publ. in Particles and Nuclei, Letters, issues 1/2 in 2001 and *Preprint hep-ph/* **0102319**.